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A Guide for Designing a Quantitative Literacy or Reasoning Curriculum

Shawna K. METZGER[1] and Philippe RAYNAL[1]

[1] University Scholars Programme, National University of Singapore

Address for Correspondence: 18 College Avenue East, #02-03 Cinammon West Learn Lobe, Singapore 138593

Email: smetzger@nus.edu.sg

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A Guide for Designing a Quantitative Literacy or Reasoning Curriculum[1]

ABSTRACT

In this article, we propose a guide for designing a quantitative curriculum in higher education institutions. Our guide consists of five key questions whose answers have substantial ramifications for the curriculum's designers when it comes to finding an approach appropriate to the institutional context. We illustrate the utility of our design guide by walking through our own efforts to design a quantitative curriculum for the University Scholars Programme (USP), a multidisciplinary honours college at the National University of Singapore (NUS).

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Over the past two decades, “quantitative literacy/reasoning” has become a buzzword in higher education, specifically in regards to students’ skills (or lack thereof) upon graduation. Ensuring that university graduates are “numerate” and “quantitatively literate”, analogous to being “word literate,” has taken on growing importance in the face of increasing demand for such individuals in a competitive, globalized workforce (Steen, 2004). Several big initiatives underscore the increasing concern with and attentiveness to quantitative skills. For instance, in October 2012, a three-group consortium[2] announced a £15.5m “Q-Step” initiative “to improve the UK’s longstanding weakness in providing quantitative understanding,” by promoting “quantitative methods training for UK social science undergraduates” (Nuffield Foundation, Higher Education Funding Council for England, & Economic and Social Research Council, 2012, p. 2). A year later, Q-Step’s funding was increased to £19.5m because of “the number and quality of the applications” received (Jump, 2013).

Responding to this demand for graduates with quantitative skills, many universities have instituted a “quantitative” requirement as part of their broader general education requirements[3]. Much has been written about specific quantitative initiatives undertaken at various universities, and the merits of these approaches (e.g., Gillman, 2006; Madison & Steen, 2007, pp. 10–13). One resounding theme emerges from these narratives: no one-size-fits-all approach exists. Yet, despite this, comparatively less has been written about how to think systematically about *designing* a quantitative requirement[4]. What sort of questions should the requirement’s designers ask, and to what end?

In this article, we develop a guide for designing a quantitative requirement. Our specific interest is in how to design an overarching curriculum for a university or programme. We view a curriculum as going beyond a simple requirement by articulating a more comprehensive vision, one that includes learning outcomes and pedagogical motivations. It often necessitates creating

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[2] The Nuffield Foundation, the Economic and Social Research Council (ESRC), and the Higher Education Funding Council for England (HEFCE).

[3] We use “quantitative” as a catch-all phrase denoting some aspect of numeracy, quantitative literacy, and/or quantitative reasoning. We discuss these distinctions further in a moment.

[4] Madison (2014) is a notable exception. He uses criteria related to the specific competencies and knowledge that the curriculum is intended to impart to guide curricular and course design. We think our guide and Madison’s should be used in tandem. Our guide speaks to structural, institutional constraints, and what types of competencies may be feasible to expect given these various constraints. Madison’s, on the other hand, addresses how to achieve specific competencies, once they are selected.

new courses to meet this vision. Our guide consists of five key questions whose answers have substantial ramifications for curriculum designers when it comes to finding the appropriate strategies for a given institution. We illustrate the utility of our design guide by walking through our own efforts to design a "quantitative" curriculum for the University Scholars Programme (USP), a multidisciplinary honours college at the National University of Singapore (NUS).

We begin by giving an overview of the "quantitative" appears in higher education—the different phrases employed in requirement/curricular discussions, and a brief overview of quantitative requirements at other universities. Second, we introduce our guide for designing a "quantitative" curriculum, and describe its parts. Third, we apply this guide to account for our design of the quantitative reasoning requirement in USP. We conclude with a few brief summary remarks.

I. QUANTITATIVE LITERACY AND REASONING IN HIGHER EDUCATION

A. Definitions

"Numeracy," "quantitative literacy," and "quantitative reasoning" are the three most common phrases that appear when discussing "quantitative" requirements. Some treat all three phrases as synonyms[5], but we believe there are subtle differences worth emphasizing. Vacher's (2014) recent psycholinguistic analysis of the phrases' usage supports our belief.

If we think of all quantitative knowledge as being arrayed a spectrum ranging from basic to complex, *numeracy* anchors the "basic" end of the spectrum. Its definition usually has two implicit, distinct parts (Vacher, 2014, p. 11):

1. A basic "skill with numbers and mathematics."
2. An "ability to read, write and understand material that includes quantitative information."

[5] Vacher's analysis (2014, p.11) suggests that all three phrases share a common dispositional element—"to engage rather than avoid quantitative information" when making decisions.

Quantitative literacy (QL) would come next on the spectrum. Its definition also has two implicit parts. One of them overlaps with numeracy, but the other suggests a slight increase in complexity with the addition of a "thinking" element (Vacher, 2014, p. 11):

1. An "ability to read, write and understand material that includes quantitative information."

2. An ability to engage in "coherent and logical thinking involving quantitative information such as mathematical relations and descriptive statistics."

Finally, *quantitative reasoning* (QR) would be the most complex of the three phrases, near the other end of the spectrum. In Vacher's analysis, its definition only contains one implicit part, which it shares with quantitative literacy (2014, p. 11):

1. An ability to engage in "coherent and logical thinking involving quantitative information such as mathematical relations and descriptive statistics."

However, in our view, an important distinction exists between the *sophistication of thinking* in QL vs. QR. In QL, "thinking" usually pertains to understanding and/or applying quantitative knowledge, at minimum. Both are middle tiers in Bloom's Taxonomy for knowledge-based outcomes (Anderson et al., 2001; Bloom, 1956). By contrast, QR "thinking" typically involves the highest tiers of Bloom's Taxonomy—it pertains to analyzing, evaluating, and creating quantitative knowledge. This lower- vs. higher-order distinction is important when thinking about designing a curriculum, because it speaks to curricular learning objectives, as we will discuss later.

Nevertheless, the above definitions highlight an important point. Mathematics and statistics are *not* synonyms for QL or QR, though they clearly play a part. Instead, the definitions underscore that QL and QR pertain to a *mindset*, one that curriculum designers are hoping to inculcate. This mindset, as Steen observes in the introductory chapter of *Mathematics in Democracy*, speaks to "an *approach* to problems that *employs and enhances* both statistics and mathematics" (emphases added, Steen, 2001, p. 5). Put differently: the central focus of QL/QR is the mindset it aims to impart, in which specific sets of quantitative tools play a *secondary, supporting* role[6].

[6] For more on QL/QR as a mode of thought, see Rossman (1997) and Schneider (2009, Chapter 1).

B. Existing quantitative requirements

We surveyed a number of universities' existing "quantitative" requirements[7]. We noticed two principal ways in which the requirements seem to manifest. These ways are not necessarily mutually exclusive, nor are the categories homogenous, and should not be read as such[8].

First, some universities reclassify existing courses as meeting the "quantitative" requirement. Examples include Cornell (College of Arts and Sciences)[9], Princeton (gen ed)[10], and Yale (gen ed)[11 12]. The corresponding curriculum is primarily aimed at developing numeracy or QL. The courses that satisfy this requirement vary widely. Introductory mathematics and statistics courses are the most common. Research design courses, offered through individual departments, also appear frequently; these courses are aimed at teaching students about the typical conventions and approaches that characterize performing research in that field of study. In more rare cases, introductory computer programming courses and philosophy courses about logic can also satisfy the requirement.

Second, some universities create new courses, or overhaul old ones, that are more tailor-made to the curriculum. Similar to how some courses are designated as "writing-intensive courses", these courses could be styled as "number-intensive courses." The corresponding curriculum is primarily aimed at developing QL or QR—i.e., the mindset, rather than a specific set of tools. Beginning to install this mindset is often the main purpose of the course, with any substantive topics or examples playing a sometimes strong,

[7] For more on other universities' efforts to develop a quantitative course and/or curriculum, see Gillman (2006) and Madison and Steen (2007, pp. 10–13).

[8] We use "course" to denote a specific offering in a university's course catalogue or registrar's bulletin, with a unique identifying code. By "class", we refer to a specific offering of the course, taught by a particular instructor in a particular semester at a particular time.

[9] http://courses.cornell.edu/content.php?catoid=22&navoid=5708.

[10] http://www.princeton.edu/ua/sections/11/.

[11] http://yalecollege.yale.edu/academics/academic-requirements.

[12] The quantitative requirement for the University of Oregon's Robert D. Clark Honors College (CHC) also falls under this category. CHC is notable because its relationship to Oregon is similar to USP's relationship to NUS; and because CHC also has some exclusive course offerings, as USP does for its students. See: http://honors.uoregon.edu/content/graduation-requirements.

yet secondary, role (e.g., Dewar, Larson, & Zachariah, 2011). While the courses are usually upper level, they can also be lower level. Examples of universities employing this type of requirement include Carleton College (gen ed)[13] and Yale-NUS College (gen ed)[14].

II. A GUIDE FOR CURRICULAR DESIGN

Student diversity (i.e., heterogeneity) is perhaps the biggest obstacle to overcome for a compulsory quantitative curriculum. Heterogeneity can come in many forms: students' comfort level with quantitative tasks, their coursework in secondary school, and their collegiate major are but a few examples. We hesitate to prescribe whether more or less heterogeneity is better. As a rule of thumb, the more heterogeneous the students are in a hypothetical class, the less complex the course's (and, therefore, the curriculum's) quantitative knowledge can be.

Our guide elucidates five structural constraints that can affect student heterogeneity. These constraints can originate from many places within the university, ranging from individual departments to major university offices (e.g., Provost, Registrar). Structural constraints, while fundamental and rather basic in nature, nonetheless have serious curricular design ramifications. Often, the constraints are beyond the designers' control, since the quantitative curriculum must fit into an existing, larger curricular structure.

We begin from the assumption that the curriculum designers are interested in developing curriculum that will, in all likelihood, necessitate creating one or more new courses. To simplify matters as we explain, we also assume that *only* these new courses will satisfy the quantitative requirement. We note where relaxing this assumption is potentially relevant.

We suggest that, *at minimum*, there are five questions that designers should ask. Each question speaks, in some way, to student heterogeneity:

Question #1: How many students will be affected by the requirement?

The more students that are affected, the more heterogeneous a given class will be, all else equal (a particularly strong assumption, in this case).

[13] http://serc.carleton.edu/quirk/CarletonResources/qr_courses.html.

[14] http://www.yale-nus.edu.sg/curriculum/student-experience/.

Question #2: What is the ideal maximum class size?

Smaller classes tend to be more homogenous, all else equal. Still, in some cases—like ours in USP—small classes can be heterogeneous in nature. In these situations, small classes can more easily allow instructors to leverage heterogeneity by discussing the material in one-on-one interactions with students.

Question #3: Are there any other compulsory courses that *all* the to-be-affected students must take? If so, what are they?

Other compulsory courses may provide unexpected, helpful leverage for quantitative curriculum designers. The quantitative curriculum can tap into key themes, concepts, and/or guides from these other courses, lessening its own content load. This also strengthens ties between the new quantitative curriculum and the existing curricular structure. Grawe and Rutz (2009) discuss how this realization helped guide their efforts at Carleton College. Our answer to this question ended up being a major driving factor for our curricular decisions in USP, too.

Question #4: Are there any other compulsory courses that only *certain subsets* of students must take? If so, what are the courses, and for which subset of students?

This is a dual-edged sword. On the one hand, if some students do have compulsory courses, and they are *quantitative* in nature, the curriculum designers could decide to permit these other courses to fulfill the curriculum's requirement. This would reduce the heterogeneity in the new, to-be-designed quantitative courses. However, if this is not an option, designers have a new dilemma—they must create a curriculum whose corresponding new courses *do not replicate* existing courses.

Question #5: Must the quantitative course be taken by a certain point in a student's study? If so, when?

This speaks to the heterogeneity among students in terms of skill. For instance, if students must take the course during their first two semesters of college, heterogeneity is relatively low. Few have taken other coursework, and in relative terms, disparities in students' quantitative skills are likely to be lowest at the start of their collegiate careers. By contrast, a mix of underclassmen and upperclassmen is arguably the most heterogeneous, because the upperclassmen's collegiate coursework will have exacerbated any initial skill disparities *and* there will still be underclassmen present.

III. APPLICATION TO USP'S QUANTITATIVE REASONING CURRICULUM

We apply our guide to the special case of developing a quantitative curriculum for the University Scholars Programme. After providing some background information about this programme, we use our guide to identify three challenging aspects of designing a quantitative curriculum for USP. We finally derive our curriculum, adapted to USP's particularities: a *quantitative reasoning* curriculum whose courses use *a substantive topic* to teach QR as a form of *argumentation*.

A. Background information

The University Scholars Programme (USP) is a multidisciplinary undergraduate honours programme at the National University of Singapore[15]. USP admits around 180 undergraduates each year, concurrent with the students' admission to one of our seven partner faculties within NUS. Our student body is diverse, with around 30% of our students in each intake coming from the Faculty of Arts and Social Sciences, around 20% each from Business, Engineering, and Science, and the remaining percent distributed across Computing, Law, and the School of Design and Environment.

USP does not grant degrees, as it is a programme, not a department. Instead, students receive a certificate of completion upon graduation. To receive a USP certificate, a USP student must:

1. Satisfy the degree requirements of his or her home faculty (i.e., his/her major)

2. Qualify for an honours degree with a grade cumulative average point of 3.5 or higher

3. Satisfy USP's requirements by taking 12 USP courses. These 12 courses are distributed across three tiers: the Foundation tier (the equivalent of introductory courses), the Inquiry tier (upper-level courses), and the Reflection tier (capstone courses).

Approximately 70% of USP students' coursework is done in their home faculties, with the remaining 30% done in USP.

[15] http://usp.nus.edu.sg/aboutusp/history.html.

There are three Foundation-tier courses: Writing and Critical Thinking (WCT), the University Scholars Seminar (USS), and the new, to-be-developed quantitative course. WCT is an existing course, and an arguable staple of the USP experience. The intensive, semester-long course focuses on the use of writing as a *means* for thinking critically about an idea, rather than simply an *end* (e.g., Geertsema, Leng, Lo, & Ryan, 2008; Lo, 2010). Students must take WCT during their first year in USP. USS is a newer course that has now congealed around the "history of intellectual inquiry." Its purpose is to familiarize students with the "key ideas, thinkers, and paradigm shifts over the course of five intellectual periods."[16] The course is two semesters long, and is taken during students' first year in USP. Importantly, all Foundation-tier courses are compulsory, beginning with the cohort matriculating in the 2012/13 academic year.

We began developing the quantitative curriculum in 2013. Our edict was twofold:

1. Our quantitative requirement would be pitched toward *quantitative reasoning.* The decision was made during the approval process for making the Foundation tier compulsory.

2. In line with USP's existing policies regarding its courses, we were tasked with developing a *self-contained* way to design our curriculum's QR course(s). In other words, all students would need to have a reasonable chance of grasping the material, regardless of their preexisting quantitative knowledge.

B. Applying our guide

The guide's five questions allowed us to identify three structural constraints relevant to designing our curriculum: multidisciplinarity, no home faculty replication, and freshmen students.

QUESTION #1: HOW MANY STUDENTS WILL BE AFFECTED BY THE REQUIREMENT?

Multidisciplinarity

Our quantitative course is a Foundation-tier course and as such, all USP students must take it. Since USP is a multidisciplinary programme, the immediate consequence is the diversity of the affected students. This heterogeneity is the first challenge that we identify.

[16] http://www.usp.nus.edu.sg/curriculum/modules/uss/uss2105/intro.html.

There are bound to be disparities in students' quantitative skills when they enroll in our quantitative course. Such heterogeneity is not unheard of in other university settings, particularly in general education courses. However, the issue is particularly acute for us, since it will *always* exist in USP, due to our multidisciplinary nature. Yet, we do not believe these differences to be insurmountable.

Heterogeneity is a challenge, but it might very well be a solution, too. Indeed, there might be an intuitive, self-contained way to teach quantitative knowledge by leveraging the strength of each cluster of students. Students comfortable with mathematics and deductive reasoning will bring their precision and logic to the class, while more humanities-inclined students, often more comfortable with inductive reasoning, will provide the necessary hindsight to grasp the wholeness of topic under scrutiny. However, such tasks require students to be able to discuss their ideas, exchange their points of view, and decide what concepts and tools would be useful. The ability to discuss is directly related to the size of the class, a question addressed below.

QUESTION #2: WHAT IS THE IDEAL MAXIMUM CLASS SIZE?

Our classes are capped at 25 students, to facilitate discussion and reflection.

In our case, our small classes still exhibit high levels of student heterogeneity, because of our programme's multidisciplinarity. Nonetheless, this restricted class size represents an opportunity for students to investigate quantitative knowledge in depth and discuss strategies to examine relevant questions on the basis of one-on-one interaction between student and professor. Students will be gradually led to introduce the required quantitative concepts, and to develop the relevant tools to think about a question and propose an answer.

QUESTION #3: ARE THERE ANY OTHER COMPULSORY COURSES THAT *ALL* THE TO-BE-AFFECTED STUDENTS MUST TAKE? IF SO, WHAT ARE THEY?

As explained previously, there are two additional compulsory Foundation-tier courses within USP: USS and WCT.

USS is only remotely related to quantitative knowledge. USS sometimes discusses one of the mindsets that QR can employ to think about a question (the scientific method). However, USS also covers other topics, such as ancient Greek worldviews and social construction.

On the other hand, WCT and QR share deeper bonds. First, at the level of USP curriculum, WCT and QR correspond to the rhetoric of words and numbers, respectively. In other words, WCT and QR represent complementary modes of argumentation: the former with words, the latter with numbers. Second, QR can use the foundations laid by WCT in terms of (1) explicating an idea and (2) elaborating an argument. This means that QR students who already attended WCT can more easily construct good arguments using QR's scientific and numeric guide.

Since USP students have different majors, there is no other compulsory course that *all* students must take, outside of our USP courses.

QUESTION #4: ARE THERE ANY OTHER COMPULSORY COURSES THAT ONLY CERTAIN SUBSETS OF STUDENTS MUST TAKE? IF SO, WHAT ARE THE COURSES, AND FOR WHICH SUBSET OF STUDENTS?

No Home Faculty Replication

Many of our students' home faculties require them to take at least one course related to quantitative knowledge. However, the nature of these requirements varies widely. Some NUS departments require their students to take courses offered through math and/or statistics, whereas others have discipline-specific research design courses.

We would like to avoid replicating the content of these extant courses in order to provide a unique perspective to our students. This is our second challenge. It is fairly unique to USP, because of how our programme is situated within NUS—i.e., we do not grant degrees; students' home departments do. At the same time, we still wanted to build off the way in which departments frame quantitative knowledge as a *means* to addressing meaningful questions about a specific subject matter. We strongly felt this would yield a QR course in line with USP's overarching mission and ethos of "intellectual rigour" and "developing interdisciplinary thinking."[17]

QUESTION #5: MUST THE QUANTITATIVE COURSE BE TAKEN BY A CERTAIN POINT IN A STUDENT'S STUDY? IF SO, WHEN?

Foundation Level: Freshmen

USP students must take QRF within their first three semesters of enrolling in USP.

Effectively, this means that the course will be populated by freshmen, with a small scattering of sophomores. This is our third challenge. Our programme does not have course prerequisites, so we cannot use

[17] http://usp.nus.edu.sg/aboutusp/index.html.

prerequisites to produce a "homogenizing effect". Further, the fact that USP students must take our QR course so early in their careers means that we cannot leverage their home faculty coursework. We are faced, quite literally, with a blank slate.

C. Our Solution

Our guide has allowed us to identify three challenges stemming from USP's unique position within NUS, either directly or indirectly: multidisciplinarity, no home faculty replication, and freshmen level. We argue that, ironically, the same uniqueness also provides us with the leverage to address them, thanks to the small size classes and the complementarity between WCT and QR. Ultimately, we arrived at a curriculum with three broad distinguishing features:

1. QR defined in terms of argumentation

2. Topic-based courses

3. Cross-course convergence, in learning outcomes, main tools, and key concepts.

i. Defining QR in terms of argumentation

The constraint from teaching at the freshmen level can be overcome by the complementarity between WCT and QR, and refining the notion of QR further by placing the emphasis on argumentation. Others have also emphasized the untapped potential of pairing QR with argumentation (Grawe & Rutz, 2009; Lutsky, 2008), with which we agree wholeheartedly. The basis for all forms of academic argumentation involves claims about the connectivity of different concepts. We believe that it is crucial for students to be able to examine the relationship between two concepts, and the problems that arise in investigating this relationship. Viewing "QR" in terms of "argumentation" helps reinforce the importance of critical engagement, and provides students with an alternative guide for conceptualizing arguments. In particular, we believe that using the scientific method as our QR mindset is important for structuring this progression in thinking. Consequently, in our curriculum, we decided to place a strong, overarching emphasis on the role of the scientific method.

ii. Topic-based courses

The additional heterogeneity of our classes led us to consider an intuitive and self-contained way to teach QR, one building on the strength of all students. A topic-based course allows such an approach. Specifically, we decided that we would offer a number of QR courses. Each QR course would explore QR through *a specific topic,* presumably from the instructor's home field. The SENCER initiative takes a similar tack (Sheardy, 2010; Sheardy & Burns, 2013). So far, we have approved courses that explore individuals' eco-footprint, how to quantify nuclear risks, how to evaluate day-to-day environmental quality, and how to assess the relationship between democracy and war.

Furthermore, a topic-based approach also provides an elegant solution to our last concern regarding the no home faculty replication constraint. To our knowledge, no quantitative courses at NUS are structured around a specific problem, and then return continually to that problem throughout the semester. Instead, the in-house courses typically provide an overview of "how to do research" in broad strokes, or they focus on giving students a "quantitative toolkit" from which they can select the best "tool" for the "job" at hand[18]. Along the way, instructors sometimes include illustrative examples, often from a wide variety of disciplines and/or situations, fictitious or real.

A topic-based approach flips this idea on its head. It teaches QR by looking at a specific way of doing research *about* a specific topic, and looking at the job in hand to figure out what tools one would need to effectively accomplish that task. In doing so, instructors encourage students to think about how the underlying principles being discussed can generalize more broadly to a problem about any topic. By employing this approach, USP's QR course *complements* existing quantitative courses, but does not replicate them. Our course's focus on the scientific method further distinguishes USP's QR course from existing courses.

Employing a topic-based approach also helps mitigate disparities in the pre-existing disciplinary knowledge among our multidisciplinary students. Our students will have different ways of thinking about a problem and different prejudices. Choosing a single topic, and discussing it in some detail,

[18] Informally, one of the common refrains we hear about such courses is that students feel like they have learned many pieces of information, but they do not see how it connects together, nor do they feel as if they know "how to do research" by the course's end. Others have echoed this point (Bos & Schneider, 2009). We recognize that this is as much a teaching problem for the instructor as it is a learning problem for the students.

provides a common point of reference for all students (Rossman, 1997, p. 52). A quantitative approach forces students to go beyond these differences by installing a common mindset, in the form of the scientific method. This mindset promotes precise definitions and objective facts, in order to rigorously investigate the question and communicate their thoughts to others.

Taught correctly (which is no mean feat, we recognize), a topic-based approach allows us to teach QR by showing how the quantitative elements under discussion, as well the logic behind them, *originate* from a substantive argument regarding some topic. All students will be exposed to—and asked to grapple with the complexities of—this substantive argument. All students thereby gain the opportunity to improve their critical thinking *and* their QR skills by approaching the material from an unconventional direction (compared to how quantitative courses are usually taught)—i.e., that of *QR as a means for critical thinking*, and not just as an end itself. We think this approach is beneficial to any student, regardless of their pre-existing QR skills (e.g., Cummins, Ritger, & Myers, 1992). However, we think it will be particularly helpful for those with weaker pre-existing quantitative skills, by helping them scaffold their facility with QR upon ways of thinking that help reveal QR's underlying logic (Buchler, 2009). This logic is not merely numerical. Instead, it involves several important steps before numbers even appear: for instance, what theoretical constructs stem from this question, how do we conceptually define these constructs, and how do we obtain reliable and valid measurements of these constructs.

iii. Cross course convergence

With a number of USP QR courses on the books, one of our biggest concerns was ensuring some sort of uniformity across them. We made three further decisions to help mitigate our own concerns.

First, all QR courses would cover three sets of tools related to: (1) the gathering and describing of numerical data, for the purpose of (2) investigating the specific relationship between two variables (at minimum)[19] and (3) the testing of hypotheses, quantitatively. This is because descriptive statistics and basic modeling are arguably the most prevalently used quantitative tools in popular media, making these skillsets relevant for *all* our students. Beyond these tools, we decided that our QR courses would not and should not

[19] This includes questions pertaining to the variables' level of analysis (Jepperson & Meyer, 2011, pp. 60–61) and possible ecological fallacies (O'Dowd, 2003), and the variables' order of magnitude ((Schneider, 2009, Chapter 2).

perfectly converge in technical content. The reason for this is simple: using a topic-based approach, what we teach *cannot* be identical, as some quantitative tools are more relevant for certain substantive topics than others.

Second, we decided that all QRF modules would at least need to touch on several QR *concepts*. We had several points we wanted to drive home to our students, regarding QR as a mode of thinking: (1) they would all be learning, in a broad sense, the same 'underlying core concepts' about the logic of QR, regardless of which QR course they took; (2) that they should start to see how and why these concepts work together in the way that they do; and (3) how to *use* those concepts in novel contexts requiring originality and independent critical thinking. Eventually, we identified 10 crucial concepts (Figure 1), and provided broad definitions of each. For more details about these "Elements of Quantitative Reasoning", see Appendix A.

1 Sm scientific method	2 Hy hypothesis	3 Sp sampling	4 Da data	5 Op operationalize
6 Va variable	7 Md modeling	8 Ay analysis	9 De deduction	10 Cr critical thinking

Figure 1. USP's Elements of Quantitative Reasoning.

Finally, we decided that all QR courses would share a core set of learning outcomes. At the end of the day, we believe that the best measure of the success (or failure) of any given teaching enterprise is a consideration of what it is that students can actually *do* now on their own, that they could not have before undertaking the course. We separated our learning outcomes into a set of broad outcomes (three, in total), and a set of more specific outcomes (four, in total). We list these outcomes in Appendix B[20].

[20] A discussion of the assessments of the learning outcomes will come in a subsequent publication.

Aside from these three crucial points, QR instructors would have a discretion in choosing which QR concepts and tools to teach, with the only provision being that their choices were justified by their course's (and the curriculum's) learning outcomes.

IV. CONCLUSION

We have provided a new guide for designing a quantitative curriculum. After clarifying possible definitional misconceptions, we have presented five questions whose answers allow curriculum's designers to identify structural constraints and potential strengths of the to-be-developed curriculum. We then consider the specific case of the QR curriculum in the University Scholars Programme, the multidisciplinary honours college at the National University of Singapore. Using our guide, we identified three challenges when designing our curriculum: the QR courses would be multidisciplinary, could not replicate other home faculty courses, and would involve all USP freshmen. We then proceed to providing an elegant solution, designing a QR course built upon three main features: (1) an emphasis on the importance of argumentation, (2) adopting a topic-based approach, and (3) convergence in learning outcomes, and key quantitative tools and concepts.

While our curriculum is only a few semesters old, we are encouraged by the results so far. Student feedback for QR courses has improved on the whole, compared to earlier, pre-curriculum iterations of the QR courses. Student evaluations contain fewer comments about "lack of a common structure" and more comments about the presence *of* said structure[21]. We intend to systematically assess our curriculum's effectiveness once we have data from more semesters. Moving forward, we are hopeful that the curriculum will create additional opportunities for our students to explore and employ QR in their studies.

[21] Favareau internal report, p. 19.

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Appendix A. Elements of Quantitative Reasoning

We decided that all QRF courses would also need to touch on several QR concepts. We forced ourselves to prioritize which concepts we thought were *crucial* for all QRF courses to cover, by assessing the concepts' importance for our conception of QR. We identified 10 such concepts, and provided broad definitions of each. To underscore the concepts' relevance, we organized them into a periodic table-like structure, and labeled them the "Elements of Quantitative Reasoning" (Figure 1)[22].

All of our students receive this document, to give them a sense of the course's overarching conceptual structure. Notably, we do not tell our instructors how, or in what order, to cover these various concepts. The numbers are mainly for identification purposes, and while the ordering reflects *a* way to discuss the concepts, it is not the only one. We also do not tell our instructors that each concept must be equally emphasized, because we recognize that some concepts will require more explication than others, depending on topic at hand. We simply require that each concept is addressed at some point in the course, and give our instructors leeway in deciding the how and when.

[22] We also chose this title in a nod to a similar document that exists for USP's WCT courses, entitled "Elements of the Essay" (Harvey, 2009).

Appendix B. Learning Outcomes

For our second key area of convergence, we decided that all QRF courses would share a core set of learning outcomes. At the end of the day, we believe that the best measure of the success (or failure) of any given teaching enterprise is a consideration of what it is that students can actually *do* now on their own, that they could not have before undertaking the course. We separated our learning outcomes into a set of broad outcomes, and a set of more specific outcomes.

For the broad outcomes, upon completion of any QRF course, students should be able to:

- Understand and be able to articulate the basic intuition and logic that undergirds quantitative analyses.
- Demonstrate how this logic can be applicable to questions in their own fields of study.
- Have become more critical consumers of quantitative knowledge through their increasing ability to read, interpret, and think critically about the use of numbers they encounter daily.
- Discuss the purpose, strengths, and weaknesses of quantitative analysis, both in the abstract, and in the consideration of any given particular phenomenon, issue, or question.

For the specific outcomes, upon completion of the QRF course, students should be able to:

- Name the steps of the scientific method as it applies to quantitative research, describe the relevant tasks associated with each step, and be able to perform these tasks correctly.
- Have a particular awareness of (1) the role that theoretical concepts and their empirical operationalization play in the research process; and (2) the importance of "falsifiability".
- Be able to: (1) build datasets by gathering and organizing numerical data, (2) compute basic descriptive statistics, (3) perform basic statistical analyses and (4) interpret the results.
- Have familiarity with the concept of "significance," in the statistical sense, and be able to explain why it is central to the very notion of quantitative reasoning.

In addition to these broad and specific objectives, we also encourage QR instructors to develop one or two learning objectives that are unique to their QR course's substantive topic. These objectives should encourage students to connect specific knowledge of the substantive topic with the QR objectives, particularly regarding QR's role in evaluating that argument. While these objectives will not be uniform across all QR courses, we think them nonetheless important for fostering the aforementioned connections. ■

ABOUT THE AUTHORS

Shawna K. METZGER is a Lecturer in the University Scholars Programme at the National University of Singapore. She is a political scientist interested in interstate conflict and political methodology. Her work has appeared in *Conflict Management and Peace Science*, *International Studies Quarterly*, and the J*ournal of Conflict Resolution*.

Philippe RAYNAL is a Lecturer in the University Scholars Programme at the National University of Singapore. He is a physicist interested in quantum information. His work has appeared in journals like *Physical Review* and the *International Journal of Quantum Information*.